What is the role for trees and vegetation in reducing air pollution?

Prof. Paul S. Monks
Perspective ....

- Air Quality Research Scientist

- Chair of the Government Science Advisory Committee for Air Quality (Defra, AQEG)

- Member of Defra Science Advisory Council
The Air Quality Expert Group (AQEG) is an Expert Committee to Defra that provides independent scientific advice on air quality, in particular the air pollutants contained in the Air Quality Strategy (AQS) for England, Scotland, Wales and Northern Ireland and those covered by the EU Directives on Ambient Air Quality.

Specifically AQEG gives advice on levels, sources and characteristics of air pollutants in the UK. It does not advise on health impacts or air quality standards.
Nitrogen dioxide (NO₂) is an important ingredient in the formation of air pollution. This map shows the global distribution of tropospheric NO₂ as observed from 2005 to 2008 by the Ozone Monitoring Instrument (OMI). Various sources of air pollution can clearly be distinguished: traffic, heavy industry, fossil fuel power plants, biomass burning, oil refineries, and shipping routes. OMI was built by The Netherlands and Finland and is onboard NASA’s Aura satellite.

Air pollution 'will become bigger global killer than dirty water'

OECD report says pollution will become biggest cause of premature death, killing an estimated 3.6 million people a year by 2050

Fiona Harvey
guardian.co.uk, Thursday 15 March 2012 17.44 GMT

Beijing, China, which is one of the countries likely to be worst hit by pollution-triggered deaths in coming decades. Photograph: David Gray/Reuters

Urban air pollution is set to become the biggest environmental cause of premature death in the coming decades, overtaking even such mass killers as poor sanitation and a lack of clean drinking water, according to a new report.

Both developed and developing countries will be hit, and by 2050, there could be 3.6 million premature deaths a year from exposure to particulate matter, most of them in China and India. But rich countries will suffer
Air Quality

“Despite considerable improvements in past decades, air pollution is still responsible for more than 400,000 premature deaths in Europe each year. It also continues to damage vegetation and ecosystems.”

EEA (2015)
BIRMINGHAM
WORKING TOWARDS A HEALTHY CITY, HEALTHY PLACE

EFFECTS OF AIR POLLUTION

IN 2010/11
891 DEATHS
linked to man-made air pollution

LINKED TO
* Cancer * Diabetes
* Asthma * Obesity
* Stroke * Dementia
* Heart Disease

Deaths due to air pollution worldwide per year

affects the vulnerable and deprived areas most

exposed to 21% higher levels of pollution

33.9% travel to work by car

BUS & TAXI DRIVERS are exposed to 3x more pollution than anyone else

CHILDREN in HIGH POLLUTION AREAS are 4x more likely to have reduced lung function when they become adults

Data sourced from: Public Health Outcomes Framework (PHE), "Every Breath We Take: the lifelong impact of air pollution" (2015 RCP & RCPCH), Marmot Cold Homes. Active Travel Survey 2015
What is the impact of Air Quality?

AQ has implications for a number of contemporary issues including:

- Human health, 
  (e.g. respiratory, cancer, allergies…),
- Eco systems (e.g. crop yields, acidification / eutrophication of natural ecosystems),
- National heritage (e.g. buildings),
- Regional climate (aerosol and ozone exhibit a strong regionality in climate forcing).
The Pollutants...

- Reactive gases: NO\textsubscript{2}, O\textsubscript{3}, SO\textsubscript{2}, ...
- Particulate matter

Nitrogen oxides (NO\textsubscript{x}) pollution

**Sources**
- Road transport: 34%*
- Near roadsides: 80%
- Energy generation: 22%*
- Domestic & Industrial combustion: 19%*
- Other transport: 17%*

*Percentage of total NO\textsubscript{x} emissions (2016) source: NAEI 2018

Exacerbates symptoms of those already suffering from lung or heart conditions shortening lives and reducing quality of life.

- High levels of NO\textsubscript{x} can change soil chemistry and affects biodiversity in sensitive habitats.
- Increases susceptibility:
  - Respiratory infections
  - Allergens

Short-term exposure to high concentrations of NO\textsubscript{2} can cause inflammation of the airways.
The Pollutants ...
Mitigation and solutions …

- Costs, benefits
- Who pays?
- Technical, non-technical
Impact of Vegetation on Urban Air Pollution

• Is there definitive observational evidence of the effectiveness of urban vegetation in mitigating air pollution?

• What role does vegetation and its effects on air pollution play in integrated urban planning and policy?

• Are the data and models to quantify effects of urban planting schemes on air quality in the major cities of the UK generally available?
Background

The urban landscape, buildings, roads, parkland, gardens….there are opportunities to change the surfaces
But space is limited and in general the scope for additional vegetation in the urban setting varies hugely and maximizing the benefit for the population should be the objective.
What do trees do …

a) Aerodynamic – trap vs. disperse (barrier)
b) Deposition to the tree (leaf) surface
Particles – Capture and Dispersion

Particles come in a range of sizes and composition.

**EFFECTS OF ULTRAFINE PARTICLES**

Atmospheric ultrafine particles (with diameter less than 0.1 micrometers) may be responsible for some of the adverse health effects observed due to air-pollutant exposure. Here's why:

**PATHWAYS INTO BODY**

Inhaled larger particles (PM10) get trapped in the tiny hairs and mucous in nose and throat. Smaller particles (PM2.5) and UFPs lodge deeper into lungs; can pass into the bloodstream.

**HUMAN HAIR THICKNESS:** 60 microns

- PM10 (1/7th thick)
- PM2.5 (1/125 thick)
- ULTRAFINES (1/100 thick)

Possible brain cancer
Could trigger heart attacks
May invade liver

People suffering from asthma and from cardiovascular diseases have been identified to be especially sensitive to air pollution. Other diseases related to UFP exposure primarily relate to lung cancer and heart disease.

* Particulate matter measuring 10 microns or smaller

**AEROSOL IMPACTION**

Streamlined air flow around object

Object

Aerosol particle

**FIGURE 19.3** Particle dry deposition velocity data for deposition on a water surface in a wind tunnel (Silton et al., 1978).
• Locally (tens to hundreds of square metres) tree planting may enhance or reduce dispersion; this **redirects pollution but does not remove it**

• Where **vegetation acts as a barrier close to a source**, concentrations immediately behind the barrier owing to that source are reduced typically by a factor of about 2 relative to those which would occur without the barrier, whereas on the source side of the barrier concentrations are increased.

• Tree planting **may also exacerbate the build-up of pollution** within street canyons by reducing air-flow
Barriers

Open road configurations

(a) Road with no vegetation barrier

(b) Road with vegetation barrier

(c) Road with green wall

Wind flow

Abhijith et al.,
AENV, 2017
Jeanjean et al, 2017, Urban Forestry and Greening

Street concentrations

a) Without trees
b) With trees (summer)

c) Aerodynamic loss

d) Deposition loss

Marylebone, London
CityScale

Undertake Computational Fluid Dynamics (CFD) at Urban Scale to assess whether trees trap or disperse pollutants.
Empirical Equation Derived

\[ \Delta PM_{2.5}(\%) = X \left( K_{t1} + K_{t2} (V_{trees})^\alpha \right) \]

Jeanjean et al, Atmos Env, 147, 1-10, 2016
Potential tree planting in the West Midlands

- Dispersion model
- Entire West Midlands conurbation
  ..Coventry Birmingham
- An extensive survey of vegetation

FPP........Future planting potential
Removal of existing trees
Planting 25% of available space
  50%
  75%
  100%........all gardens, parks, verges, green space, sports grounds.
**PM$_{10}$ reductions for 4 planting scenarios**

<table>
<thead>
<tr>
<th>Scenario</th>
<th>%Change</th>
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<tbody>
<tr>
<td>No trees</td>
<td>4%</td>
</tr>
<tr>
<td>FPP25</td>
<td>-10%</td>
</tr>
<tr>
<td>FPP50</td>
<td>-17%</td>
</tr>
<tr>
<td>FPP75</td>
<td>-22%</td>
</tr>
<tr>
<td>FPP100</td>
<td>-26%</td>
</tr>
</tbody>
</table>

McDonald et al, Atmos Env. 2007
Capturing energy from sunlight to neutralise pollution

Nitrogen oxides absorb energy from UV in sunlight. Nitrogen oxides adsorbed onto the particles are converted to nitric acid.

The acid then reacts with calcium carbonate, locking the NOx gases up as calcium nitrate, releasing CO2 and water.

### Centreline NOx concentration

<table>
<thead>
<tr>
<th>distance across London (km)</th>
<th>NOx concentration (µg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>15</td>
</tr>
<tr>
<td>10</td>
<td>20</td>
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<tr>
<td>20</td>
<td>25</td>
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<td>40</td>
<td>35</td>
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<tr>
<td>50</td>
<td>40</td>
</tr>
</tbody>
</table>

Legend:
- **no paint, no background**
- **with paint no background**
- **no paint, including background**
- **with paint, including background**

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**Paints and Surfaces for the Removal of Nitrogen Oxides**

Prepared for:
- Department for Environment, Food and Rural Affairs
- Scottish Government
- Welsh Government
- and Department of the Environment in Northern Ireland
Mitigation in the urban environment - Oxford St, London

Full lifecycle analysis of six mitigation strategies using CFD (Jeanjean et al, 2017)
CONCLUSIONS

• Overall, vegetation and trees in particular are regarded as beneficial for air quality, but they are not a solution to the air quality problems at a city scale.

• It is unlikely that large reductions in concentration (>20% for PM$_{2.5}$) could be achieved using vegetation to enhance deposition over a substantial area.

• For nitrogen dioxide (NO$_2$), vegetation is, generally speaking, of little benefit; it is not a very efficient sink. The deposition occurs in daytime, and primarily in the warmer months, when NO$_2$ is less of a problem.
Other things ...

- The use of trees to improve air quality is not without negative impacts as some tree species are important sources of biogenic volatile organic compounds (BVOCs), notably isoprene.

- However, BVOC emissions could be avoided by selecting low emitting species.

- Similarly, the choice of plant species which are known sources of aeroallergens should be avoided.
Important Paradigm for Air Quality

- Compared with emissions control at source, removing pollutants once diluted into the atmosphere is challenging because of the large volume of air into which the pollutants have been dispersed compared to the surface area to which any potential abatement technology may be applied.